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Final Report

NASA - Ames University Consortium Interchange NCC2-5048:

Construction of Grey Atmosphere Models for Uranus and Neptune

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I. Background

The atmosphere of a giant planet acts somewhat like a thermostat, controlling the rate at which thermal energy is radiated into space. As energy is radiated away, the interior of the planet cools and its radius decreases. Thus a calculation of the thermal evolution of the interior of a giant planet must rely upon a model of the planet's atmosphere. The difficulty is that as the heat flow from the planet changes with time, the atmosphere also cools. A single evolutionary calculation must rely upon literally hundreds of individual model atmosphere calculations. Producing these necessary models of the 'ancient' atmosphere of, say, Saturn is both time consuming and difficult. The research conducted under this interchange addresses this problem.

The original research plan had been to modify an existing model atmosphere code developed by the PI by incorporating a new algorithm for utilizing Rosseland mean opacities developed by Dr. Jim Pollack. This new routine would permit the calculation of multiple Uranus and Neptune atmosphere models for incorporation into evolutionary calculations. Unfortunately Dr. Pollack passed away during the period of my residence at Ames this summer. We had not yet finalized the algorithm at the time of his death. Subsequently I continued this research in collaboration with Dr. Chris McKay who had been another Ames collaborator on this project and is working on a similar program for Titan.

Given that Dr. McKay and I are working on similar problems, we decided to follow a somewhat different program than had originally been planned to better coordinate our two projects. Instead of replacing the approximately 100 spectral intervals in the current code with a gray atmosphere calculation, we decided to keep the code essentially unchanged. However the central problem for which the Rosseland mean opacity had been suggested as a solution, overlapping molecular opacities in a single spectral interval, remained. For the evolutionary calculations opacities of H_2O, CH_4, and NH_3 must be included. In some spectral regions two or more of these molecules have overlapping opacities. The current code, however, can properly handle only a single molecular opacity per spectral interval. Resolution of this problem without relying upon mean opacities thus became the central topic of research during the PI's residence at Ames.

Finally, the impact of Comet Shoemaker-Levy/9 with Jupiter provided a spectacular opportunity to test the radiative transfer code. The impact deposited a significant quantity of dust into the stratosphere of Jupiter. The dust was observed to affect the equilibrium temperature structure of the atmosphere. In the future the radiative-convective model developed under this program will be applied to Jupiter to compare the model calculations with the observed heating. To take advantage of this unexpected opportunity, approximately 20% of the project time was devoted to preparations for and observations of the comet impact.

II. Progress

Unfortunately the death of Dr. Pollack and the associated change in approach delayed the research. Thus while significant progress was made during the interchange agreement towards the goals outlined above, the research was not fully completed. Below I outline the accomplishments achieved during the interchange period and discuss the work yet to be done.

Ames researcher Richard Freedman maintains a spectroscopic database from which the opacities required for this project have been obtained. We worked to define an appropriate grid of pressure, temperature, and composition upon which to generate individual cumulative probability distributions for the molecules of interest from this database. At each grid point the exponential-sum opacity coefficients are calculated for each molecule. The task is then to construct an algorithm to interpolate from the individual exponential sum coefficients on the grid a set of exponential-sum coefficients accounting for the mixing. In other words, we desire a routine that provides $S_i = S_i(P,T,X_j)$ where S_i is the i^{th} exponential-sum coefficient, P is the pressure, T is the temperature, and X_j is the mixing ratio of each of the optically active gasses in a given model layer. Since there are three gasses of interest and eight terms in the exponential sum, we must interpolate eight different quantities within a five dimensional parameter space. This task turned out to be quite difficult, but excellent progress has been made. We are now testing several interpolation schemes to determine which best reproduces the input dataset.

The advantage of this new technique is that the resulting coefficients S_i have the same appearance to the atmosphere code as the coefficients arising from a single molecular absorber. Thus with only minor modification (to keep track of the vertical profile of each absorber) the code can properly model opacities from several absorbers instead of only one. The necessary modifications to the atmosphere code have been made and the code now accepts as input the output from the above interpolation routine. Since a larger range of pressure temperature space must be explored in evolutionary calculations, the pressure/temperature regime acceptable to the atmosphere codes has been likewise been expanded. In addition several further refinements, regarding the treatment of ortho and para hydrogen as well as the hydrogen opacity were incorporated. Thus while the computational method has been changed, the goals of the research program will still be met. Once the interpolation routine is complete the necessary model runs required for the evolutionary calculation will be initiated.

In parallel with the above tasks, development continued on the evolutionary code that ultimately will incorporate the results of the atmosphere calculation. This code utilizes a relaxation technique to satisfy the differential equations governing the thermal evolution of a planet. The framework of this code has now been written and tested. Further development is required, however, before the code will be complete. Development must proceed in consort with the atmosphere modeling code since the two routines will ultimately be closely linked. NMSU graduate student Susan Lederer is conducting this work under the direction of the PI.

Finally data has been acquired from the impact of comet Shoemaker-Levy/9 into Jupiter. While not strictly a part of the interchange task, this work will serve to directly test the atmosphere model developed under this program and was thus judged of high importance. NMSU graduate student Nancy Chanover and I observed the impacts from the Apache Point Observatory 3.5m telescope in Sunspot NM with a near infrared array camera. We obtained several hundred images in narrow band filters between 1.4 and 2.4μm. Along with visible images obtained at NMSU's planetary telescope, these images will be used to constrain the vertical distribution and optical properties of the impact ejecta. Also I participated in a program of thermal infrared imaging of Jupiter from NASA's infrared telescope facility. These images will provide information on the altered temperature structure of Jupiter's atmosphere. Thus by combining information from the near-IR and thermal-IR images we can produce a direct test of the code discussed above. The data reduction and code testing is a task for the future.

In conclusion, signficant progress has been made over the course of the interchange agreement towards the development of the atmosphere boundary condition code. It is expected that the complete code incorporating the new opacity treatment will be completed in the next several months.